METHODS FOR THE MINERALOGICAL AND TEXTURAL ANALYSIS OF COMET NUCLEUS SAMPLES; D. Stöffler, H. Düren and J. Knölker, Institut für Planetologie, Universität Münster, D-4400 Münster, Germany.

This abstract attempts to review the objectives and instrumental requirements of a petrographic analysis of porous comet nucleus material. It is organized in four main sections which will deal with (I) the objectives of the petrographic analysis of cometary material, (II) the assumptions about its composition and texture, (III) the available techniques for the microscopic analysis of comet analogue material, and (IV) new techniques required for the petrographic investigation of natural and artificial comet nucleus samples.

I. Objectives of the petrographic analysis of returned comet nucleus material

In the context of the Comet Nucleus Sample Return Mission ROSETTA (1) the petrographic laboratory analysis of returned samples under the conditions of the parent comet nucleus is fundamental for any further chemical, isotopic, and physical analysis of the bulk sample and its constituent phases. It is also a prerequisite for the intelligent allocation of sample aliquots to specialized investigators in sophisticated terrestrial laboratories. The petrographic analysis of cometary material must be capable of characterizing various properties of the bulk samples quantitatively. It must also provide ways of identifying the constituent phases and composite textural subunits of the sample. For the bulk sample one needs to know (1) the type and abundance of the constituents (inorganic minerals, ices and clathrates, carbonaceous material, and aggregations of these considered as textural subunits) and (2) the textural properties such as the grain size distribution, morphology and intergrowth characteristics of the constituents; anisotropy of distribution and orientation of the constituents; porosity. The constituent phases must be characterized by their chemical composition and structural state.

II. Assumptions about the composition and texture of comet nucleus samples

The application and development of instrumental techniques which will meet the objectives defined above, requires a model of the composition and texture of comet nucleus material. Information which is relevant for such a model, can be obtained from direct observations of comets and interstellar dust, from the study of primitive solar system material (e.g. cosmic dust and primitive meteorites), from the theory of grain formation in solar and stellar nebulae and from accretion and evolution models of comets (2, 3, 4). Our best estimate of the expected main constituents of a comet nucleus are the following: (a) ice crystals including clathrates (H_2O, CO_2, CO, CH_4, NH_3 etc.), (b) inorganic minerals such as silicates (olivine, pyroxene, sheet silicates), oxides, sulfides, carbides, metal and others, (c) carbonaceous matter ranging from amorphous and crystalline carbon to hydrocarbons of variable composition and degree of polymerisation, (d) "rock-like" aggregates of inorganic minerals and carbonaceous matter, (e) aggregates of ices and all types of refractory constituents (b), (c), (d) and (e).

One can expect a variety of textural characteristics of the samples. These include coating of inorganic phases by carbonaceous material, porous to fluffy aggregation of ices and refractories, small grain size of the individual crystals (< 10 µm, with most grains < 1 µm), large variation of the size of aggregates (possibly from µm to dm or m), and preferred orientation and anisotropic distribution of the constituents (layering, accretion textures etc.).

III. Presently available techniques for the microscopic analysis of porous ice-mineral mixtures

Methods for the microscopic analysis of weakly coherent snow and solid ice in polished sections and thin sections have been developed by workers in the snow, ice, and avalanche research areas since the late 1930's (e.g. (5), (6) and papers in (7)). The basic principle of the preparation of polished sections and thin sections is to impregnate the porous snow sample with an organic liquid having a freezing point below the freezing point of H_2O and to crystallize this liquid at lower temperatures. This allows the sample to be cut and thin sections to be produced by a microtome technique. A stereometric analysis can then be made by an automated image analysis of micrographs obtained by any type of microscope in reflected or transmitted light (7).

This method yields the complete set of modal and textural data discussed in section II. The most advanced information about the three-dimensional structure of the sample results from the stereometric analysis of serial cuts (7) which are taken at increasing depths of the sample (with a constant spacing of some tens of µm or less).

The microtome technique applied by snow researchers can be used for comet nucleus analogue materials only if the enclosed refractory minerals have a Mohs hardness similar to that of ice (~ 1.5 - 2), e.g. for mixtures of ice or snow and sheet silicates. We have made first successful tests to prepare thin sections of ice-olivine and snow-olivine-smectite-carbon mixtures with a special microtome equipped by a rotating double-diamond milling head.

The preparation of thin sections and polished sections of synthetic cometary material has been performed so far in a low temperature laboratory with two rooms kept at different temperatures (~ 268 K and ~258 K). The sections can be studied either with microscopes used inside the cold laboratory at temperatures as low as ~235 K or with microscopes equipped with cryostat cells which easily allow temperatures as low as ~ 80 K (liquid nitrogen). However, a preparation method for microscopic sections at comet nucleus temperatures is not yet available.

IV. Required new techniques for the petrographic analysis of natural and artificial comet nucleus samples

The petrographic characterization of returned comet nucleus samples will be an integral part of a curatorial facility required for handling, preliminary examination, and distribution of such samples to specialized investigators. A possible curatorial system is visualized in a simplified and schematic flow diagram (Fig. 1) which may illustrate the needs for specific techniques. Some major instrumental developments for the petrographic analysis are tentatively summarized as follows: (a) Handling of samples under cometary conditions (vacuum; 100 - 200 K temperature range; clean chemical conditions; preservation of texture) by a system a cryostat locks and cabinets with remote manipulators, (b) preparation techniques for consolidating, cutting, thin sectioning and polishing comet nucleus samples at temperatures<230 K, (c) techniques for the non-destructive textural and modal characterization ("tomographic" methods), (d) techniques for the remotely operated separation of the constituents of a bulk cometary sample.

REFERENCES: (1) ROSETTA, The comet Nucleus Sample Return Mission, Report of the Joint ESA/NASA Science Definition Team Space Science Department of ESA, ESTEC, Noordwijk, The Netherlands, SCI (87) 3, 1987. (2) Wilkening L.L. (ed.) (1983) Comets, The University of Arizona Press, Tucson, Arizona. (3) Grewing M., Praderie F., and Reinhard R. (eds.) (1988) Exploration of Halley's Comet, Spinger Verlag, Berlin. (4) The Comet Nucleus Sample Return Mission, Proceed. ESA Workshop, Canterbury, U.K., 15-17 July 1986, ESA SP-249, ESTEC, Noordwijk, The Netherlands, 1986. (5) Bader H., Haefeli R., Bucher, E., Neher J., Eckel O., Thams C., and Niggli P. (1939) Der Schnee und seine Metamorphose (Snow and its Metamorphism), Transl. 14, US Snow, Ice, Permafrost Res. Establ. Wilmette, Il. (7) Avalanche Formations, Movement and Effects (1987) Proceed. Davos Symposium 1986, IAHS Publ. No. 162, 1987. (6) Good W. (1982) Z. Gletscherk. Glazialgeol. 18, p. 53-64.

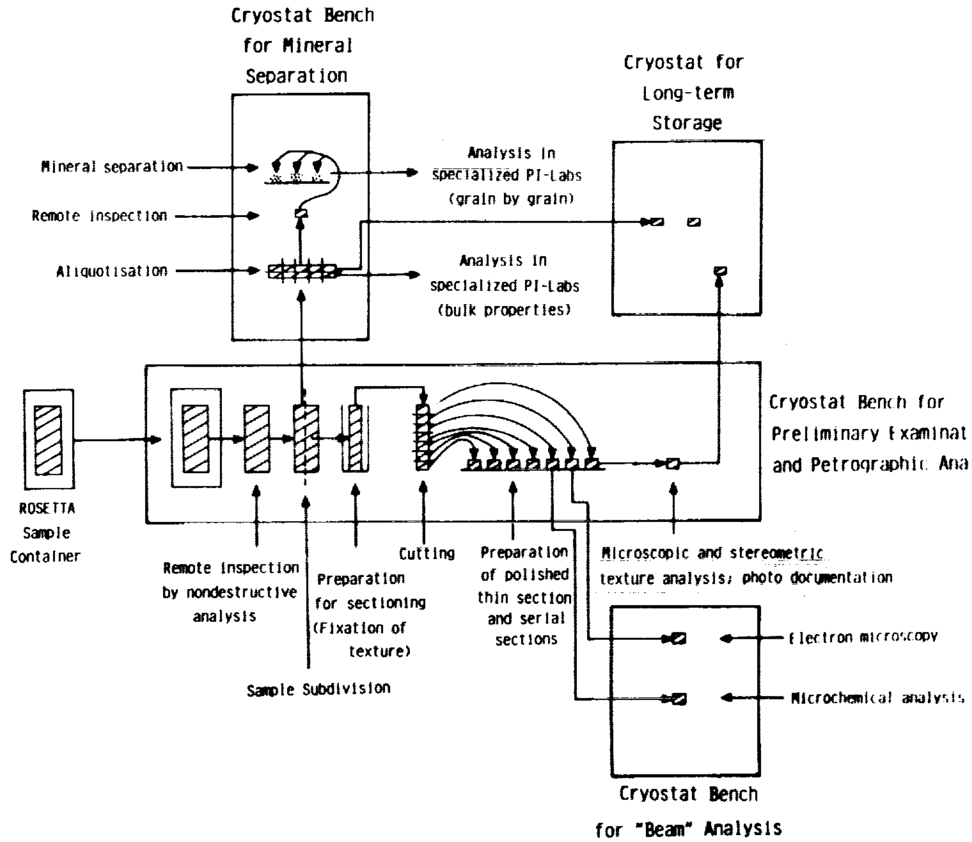

Fig. 1. Flow diagram for the curation and petrographic characterization of comet nucleus samples